LCA Case Studies

Environmental Considerations on Battery-Housing Recovery

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Abstract

A simplified LCA is conducted based on the methodology of simplified LCAs according to SETAC (Europe). The case study is about the recovery of automotive battery housings. As a result of the simplified LCA, the current situation of material recycling is preferred to the past situation of landfilling. However, energy recovery could be an option, too.

Keywords: Recycling; recovery; streamlining; screening; plastics; automotive

1 Introduction

The German automotive manufacturers have released a commitment on a very challenging voluntary agreement regarding recovery rates of their products. The plan is to ensure a recovery of 95% in the year 2015. A draft EU directive plans similar quotas. For comparison: today 80% of each Ford Escort is recovered. To achieve the voluntary agreement, more and more non-metal components have to be recycled. A special task is the recycling of non-metals as, for example, plastics that represent up-to 50% of shredder residues (light fraction). Where available, Ford aims at using recycled plastics with a minimum of 25% recycled post-consumer plastics.

One example is the existing mechanical recycling of battery housings. Due to the dismantling of batteries, battery housings can be easily separated as a pure fraction. The battery housings of Ford vehicles are made out of polypropylene. In autumn 1998, the 100,000th battery housing is recycled in a closed-loop in cooperation with Britannia Recycling in the United Kingdom. Today, the content of recycled post-consumer plastics of the battery housings is 100%. In the past, the battery housings were cleaned (from the battery acids) and discharged to landfills in UK.

However, the costs of mechanical recycling are high compared to the price of new polypropylene while the value for the environment is unknown and should be checked. Due to limitations in resources, no "full" LCA could be performed. A simplified LCA should increase internal knowledge. Consequently, no external, but an internal critical review has taken place.

2 Methodology

Several proposals for a simplification of LCAs are known (e.g. [1], [2], [5]). The methodology recommended by the Society of Environmental Toxicology and Chemistry (SETAC) Europe Working Group for Screening & Streamlining LCA [3] is applied. The reason for this choice of methodology has been the limitations in resources as well as the strategic objective to get more information on the feasibility, value and meaningfulness of "quick" methodologies (compare [4]). The SETAC working group proposes a three step procedure (screening, simplifying, reliability assessment) that has to be applied to the whole LCA procedure according to ISO [6] (→ *Fig. 1*).

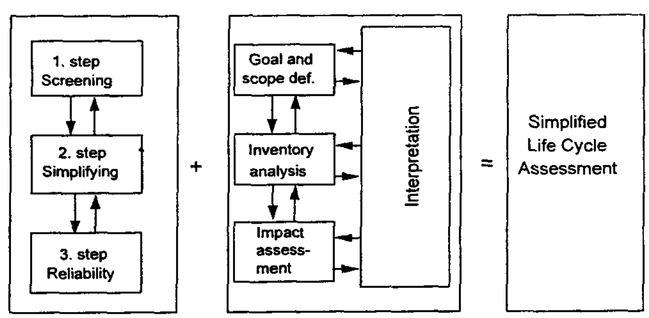

Fig. 1: Simplified Life Cycle Assessment according to SETAC Europe

2.1 Screening

During a goal and scope definition a screening has to be performed to find data and processes that should be inside or could be left outside the study (screen in or out). The following screening indicators may help the practitioner to meet this task:

- Cumulative Energy Demand, CED [7]
- Resource Consumption, e.g. Material Intensity Per Service unit [8]
- Key substances that are typical for the examined product group (e.g. CFC, heavy metals, GWP)
- ABC assessment to identify "red flags" (A: environmentally high relevance, C: low [9]).

However, care needs to be exerted when using screening indicators. It has to be ensured that all environmentally important aspects of the product life cycle are taken into account. This is not the case if either resource or energy consumption or single key substances are the sole screening indicators (→ *Fig. 2*). In this context, the combination of screening indicators (looking at inputs and outputs) will increase the reliability of screening. Other screening indicators which do not include a life cycle perspective cannot be applied to all stages of the life cycle (percent of recycled material, recyclability or degradability which focus at life cycle stages after consumption of products) and should not alone be applied for screening.

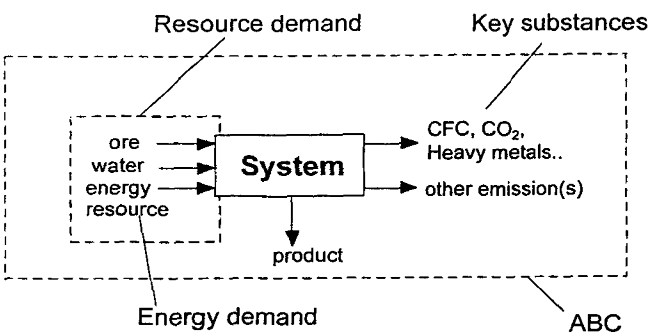

Fig. 2: Elementary flows considered by the different screening indicators [3]

In the automotive industry, different indicators are already used. The calculation of the cumulative energy demand is done for several European cars (e.g. [10]).

2.2 Simplifying

The second step (simplifying) is particularly useful at the inventory stage, but there are also simplified approaches for impact assessment. Streamlining or simplification is possible at [11]:

- System level (whole life cycle), by cutting off e.g.:
  - upstream processes (prior to final material manufacture)
  - downstream processes (after final material manufacture)
  - similar or identical life cycle phases
  - insignificant processes
  - processes going in the right direction (for comparative LCAs: if A is clearly better than B, not all processes of B have to be taken into account).
- Process level, for example, by cutting off:
  - all / selected inputs
  - all / selected outputs
  - insignificant / similar inputs or outputs.
- Data level, by use of:
  - secondary data
  - surrogate data
  - qualitative data.

2.3 Reliability assessment

The aim of simplification in LCA is to derive results that are sufficiently reliable for the required purpose, while putting in less effort than in a full LCA study. In order to check that a simplified LCA achieves this, the final step in a simplified LCA needs to be a reliability assessment (see also ISO 14043 draft) consisting, for example, of:

- scenario techniques
- dominance analysis
- sensitivity analysis.

3 Case Study On Battery Housing Recycling

3.1 Goal & Scope Definition and screening

Batteries are recycled first and foremost for their lead content, although the recycling of all parts of a vehicle has to be checked to achieve the challenging recycling quota (see chapter 1). This case study is on the closed-loop recycling of ca. 500 g of polypropylene per battery housing. Intensive technical checks have indicated that there is no technical or functional difference between battery housings using primary or closed-loop recycled polypropylene, neither in terms of quality nor of weight. The goal of the study has been to increase knowledge on the environmental benefits of this kind of material, closed-loop recycling, as well as the strategic interest in enlarged experiences of "quick" LCAs.

The functional unit is 100,000 PP of battery housings (see chapter 1) as specified by Ford's material engineers. No external review according to ISO is performed due to the goal of the study. However, an internal review has been performed by the Ford Department on Vehicle Recycling. In addition, the study has been provided to Britannia Recycling.

The system boundaries and basic assumptions are reflected in **Figure 3**. The geographical, technological and temporal reference is the current situation (as far as possible) in the United Kingdom. All allocations are performed related to mass. The open-loop allocation regarding a scenario on energy recovery (chapter 3.3.1) is handled by an expanding of the system (compare the draft of ISO 14041, B 1.2, example 3).

The base scenario is the comparison between the current situation (mechanical closed-loop recycling) and the past

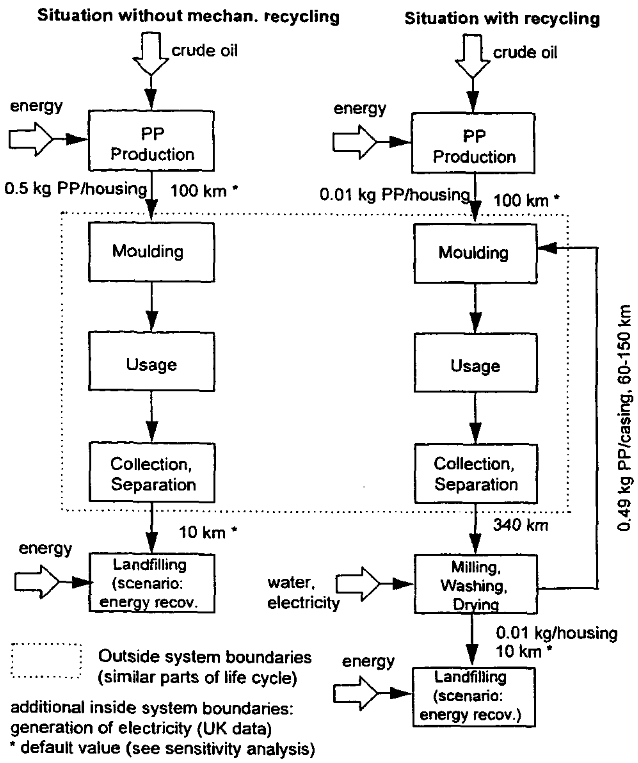

Fig. 3: System boundaries and basic data

situation (landfilling). An additional, theoretical scenario is the energy recovery of the battery housings.

Considering a qualitative screening (ABC, [9]), the battery case moulding, usage and collection are screened out due to negligible differences between the compared systems. Energy generation and transports can be important. Lead emissions of the washing process may be important. In screening, data gaps are identified (for example no data of Pb emissions, water consumption, waste water). An energy screening (see chapter 2.1) supports the cutting off and stresses the importance of specific data for mechanical recycling as well as the importance of PP production (scenario without mechanical recycling).

3.2 Simplified Inventory and impact assessment

3.2.1 Data sources and simplification

On a system level as a simplification for studying battery housing moulding, usage and collection are cut off due to the conclusions of screening.
The data sources are specific for transportation distances and mechanical recycling. Default values have to be used for transport distances between primary PP-production to moulding and to disposal. For electricity production, UK-specific data is used. All other data comes from public data bases ([12 – 14]). To ensure data symmetry the data is restricted to all elementary flows contributing to:

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- aquatic Eutrophication / Nitrification Potential (NP_a)
- terrestrial Eutrophication / Nitrification Pot. (NP_t;)
- Resource Depletion Potential (RDP)
- total amount of waste and Cumulativ Energy Demand (CED).

CED is calculated according to VDI [7] (with and without feedstock energy), impact categories according to accepted indicators [15], and total waste is a not weighted sum of all waste categories (i.e. without differentiation between different qualities of waste). Due to data gaps and asymmetry of data, no toxic releases could be regarded.

3.2.2 Results

The net benefit of the current mechanical recycling (compared to landfilling them in the past) is shown in Figure 4

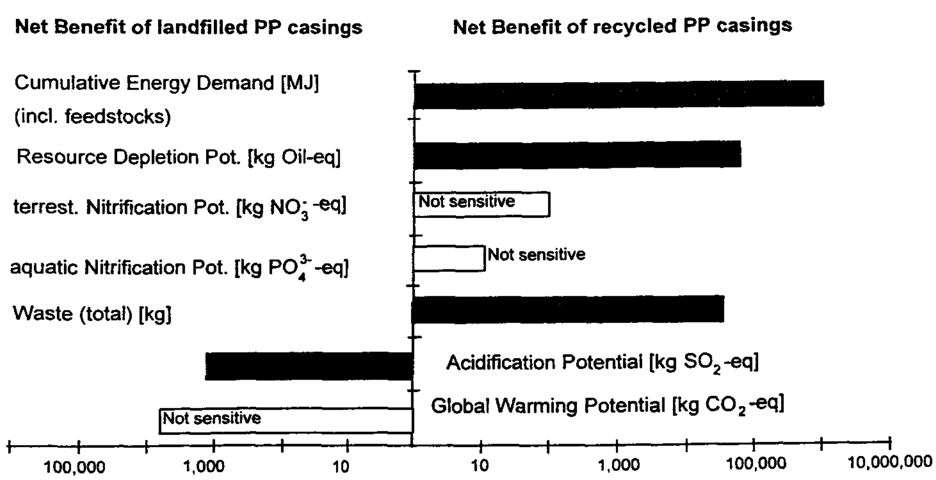

Fig. 4: Recycling of 100,000 battery cases: net benefit for the environment compared to landfilling (calculation using the maximal distance for mechanical recycling; for sensitivity see chapter 3.3.1 (b))

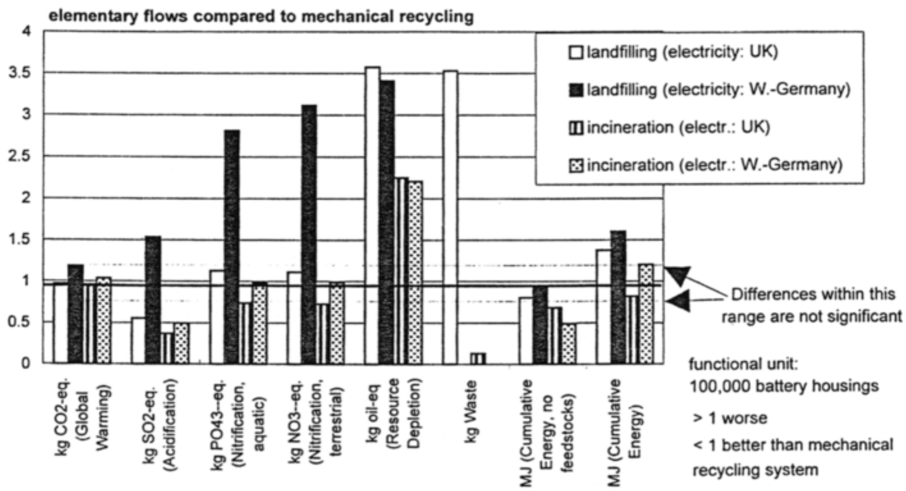

Fig. 5: Four scenarios of environmental comparisons: Mechanical recycling of 100,000 battery cases (= 1) compared with disposal (calculation using the minimum distance for recycling)

(logarithmic scale!). According to these results, mechanical recycling is better than landfilling in terms of cumulative energy demand (includes feedstock energy), resource depletion, nitrification and total amount of waste. Acidification and global warming, on the other hand, are higher for material recycling. In spite of the availability of two different LCA softwares at Ford Motor Co., no LCA software has been used for this case study.

3.3 Reliability Assessment

3.3.1 Scenarios

In different scenarios the analysed situation in UK is compared with the situation in other countries. An important environmental question is what would happen if PP housings are going to energy recovery instead of landfilling (assumption: energy efficiency of 30% in energy generation, 33.9 MJ of usable energy/kg PP). Another interesting scenario is to change the mix of power stations. In a scenario, the energy mix of Western Germany is used [14] instead of the energy mix of UK (note: the UK data are older data from ca. 1989). Incineration of the examined battery casings is better than material recycling in terms of nitrification, acidification, cumulative energy demand and total amount of waste. Global Warming Potential of incineration and material recycling of PP battery casings is similar (reasons: see dominance analysis). Only resource depletion potential is better for material recycling (→ *Fig. 5*). The reason for this disadvantage of incineration is that much more crude oil is used than in the system of recycling (recycled material saves crude oil consumption of the PP production).

If Western German energy data is used, the environmental advantage of recycling as compared to that in (older) UK energy data is increased (→ *Fig. 6*) due to fewer environmental burdens. However, resource depletion is decreased by this scenario due to the inclusion of more resources in inventory (e.g. iron for the construction of power plants). The main source for differences between the two scenarios is that the older UK data indicates higher elementary flow, especially in terms of acidification and nitrification (ca. factor 3), due to older technology and (especially regarding acidification) another energy mix. The difference in terms of resource deple-

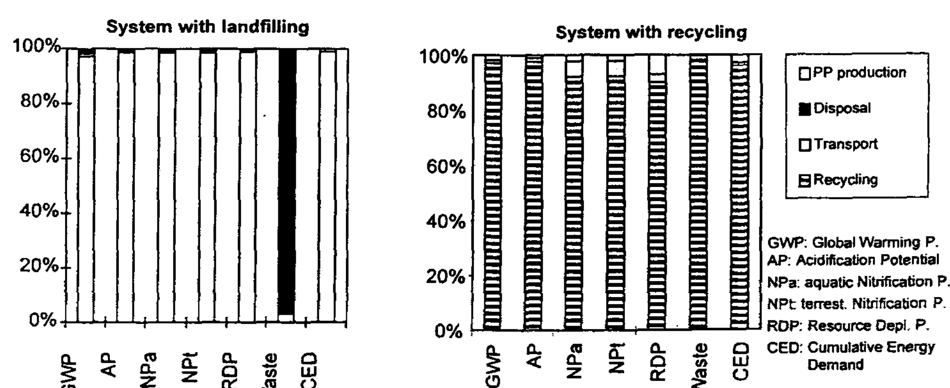

Fig. 6: Dominance analysis of the base scenario: Sources of environmental burdens of the system with and without recycling

tion is originated in different system boundaries of the data set. As one result of the scenario analysis, it has to be stated that the symmetry of data is not given if the German electricity data is included (i.e. broader system boundaries, more data categories, etc. included for the German electricity data) and that the available UK electricity data is not up-to-date (due to a higher share of gas than coal-based electricity, the advantage of energy recovery will be even higher; this will be considered for the interpretation of the results).

a) Dominance analysis

By a dominance analysis, these sources of environmental burdens are identified that dominate the overall result. Looking at the base scenario (UK, recycling vs. landfilling), the PP production dominates the result of the system without recycling (exception: waste). In the case of battery recycling, the energy consumption of the recycling process itself results in ca. 90 to over 97% of the overall environmental burdens; the rest is caused by transport and replacement of recycling losses by virgin PP (→ *Fig. 6*). All of the environmental burdens of the recycling process are caused by electricity consumption (no other data available).

Looking at the incineration scenario (UK electricity data), the share of incineration is high for global warming (due to burning of PP) and waste (due to ash, waste of filter systems, etc.). Due to incineration, a credit exists for the cumulative energy demand. In this scenario, ca. 56-60% of the recycling system is dominated by the (electricity consumption of the) recycling process itself (Cumulative energy demand (CED, [7]): the share is ca. 66% because of the energy that is produced in the complementary energy production; the generated amount of energy has a negative sign). The complementary energy production (generating the same amount of energy as the incineration system) has a share of ca. 38-40% of the environmental burdens (CED: ca. 32%). This amount is the reason for the disadvantage of material recycling (see above).

b) Sensitivity analysis

Considering the dominance analysis, the sensitivities of the data, and assumptions concerning energy consumption and losses of the recycling process, the transport distances as well as the efficiency of incineration (influencing the amount of the complementary power plant process) are interesting (→ *Fig. 7*). The elasticity (E) of (for example the electricity) the data of recycling is equal to the ratio of change in the overall result [%](C_R) of changes in electricity data [%] (C_D) (equation 1).

$$E = \frac{C_R}{C_D} \tag{1}$$

The higher the elasticity, the more sensitive is this data for the regarded impact category. The numbers in **Table 1**, for example, can be read as: If the real transport distance during recycling was doubled (compared to this simplified LCA), the overall net benefit for environment given as Global Warming Potential (GWP) would be only 0.3 times higher than identified in **Figure 4**. A positive figure indicates that the benefit of energy recovery is increased, while a negative figure indicates that the benefit of recycling is decreased.

The results of sensitivity analysis (→ *Table 1*) are:

- transport distances of the recycling system are not sensitive data, i.e. this data does not significantly influence the overall result if it differs in a small range
- least sensitive impact category is the Resource Depletion Potential
- the elasticity of electricity is above 1, i.e. the life cycle system boosts data uncertainties. The reason is the dominance of electricity data for the recycling system (see dominance analysis)
- the elasticity of recycling yield is above 1 concerning Global Warming Potential
- the elasticity of efficiency of incineration is above 1 concerning Global Warming, aquatic Nitrification and cumulative energy demand.

It has to be stated that the data for electricity generation is specific for UK, but not up-to-date. The data for electricity consumption is a specific data. It can be assumed that this data varies max. ± 10% due to measurement faults. This would result in a change in the net benefits of about 695% (Global Warming), 46% (Acidification), 151% (aquatic Nitrification), 172% (terrestrial Nitrification), 7% (Resource Depletion), 8% (Waste) and 54% (Energy). The environmental burdens of the system with material recycling increase of ca. 20% (all

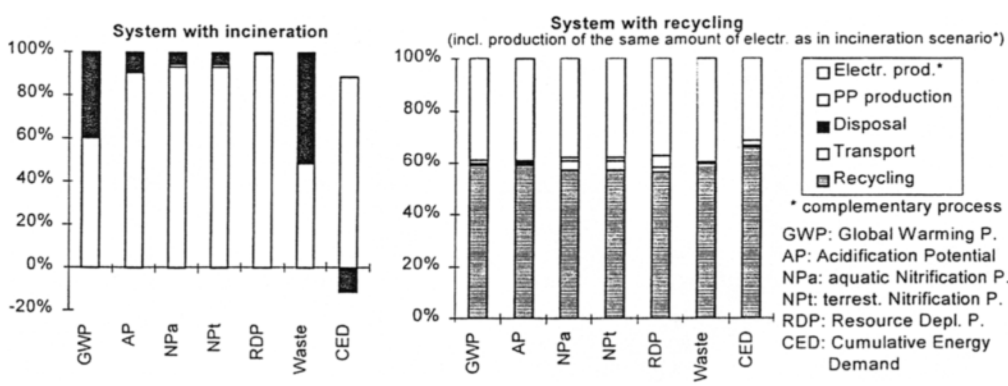

Fig. 7: Dominance analysis of the incineration scenario (UK data): Sources of environmental burdens of the system with and without recycling

Table 1: Elasticity of basic data (changes for net benefits)

Elasticity of	GWP	AP	NPa	NPt	RDP	Waste	CED
Rec. transport distance (820 km instead of 410 km)	0.30	0.03	-0.37	-0.42	-0.01	0.00	-0.03
Electricity (4.18 instead of 2.09 kWh/kg)	99.24	6.55	-21.52	-24.59	-1.05	-1.88	-7.66
Recycling yield (0.88 instead of 0.98)	3.23	0.12	-0.86	-0.97	-0.14	0.00	-0.36
Efficiency of incineration (0.6 instead of 0.3)	10.29	0.62	1.45	1.39	-0.30	0.54	1.87

impact categories, waste and energy) by this change in electricity consumption (+ 10%). Consequently, conclusions should not be done in terms of Global Warming and Nitrification. In addition, the acidification of electricity production is overestimated due to the probably of data which is not-up-to date. The data of the system without recycling has a relatively higher acceptance of data (data of APME). Therefore, no sensitivity analysis for the dominating PP production is done.

4 Conclusions

Due to the sensitivity analysis, only differences above ± 20% indicate an environmental net benefit. Advantages below ± 20% are within the range of uncertainty. According to sensitivity analysis, the exact figures of net benefits are uncertain (especially concerning global warming and nitrification). However, regarding all scenarios (including up-to date electricity data), a qualitative statement is possible that:

- the current situation of mechanical recycling is better than the past landfilling of battery housings in terms of resource depletion, total amount of waste and cumulative energy demand, and may be acidification and nitrification. The last two environmental themes are especially true if the elementary flows of the electricity production in Germany are used for calculation.
- However, if UK electricity data is used, landfilling of battery casings is better in terms of acidification. In fact, this disadvantage will be significantly smaller if up-to-date data is used.
- According to the given data, the energy recovery of battery housings would be better for the UK in terms of all considered impact categories (exception: higher resource depletion, similar global warming; due to the substitution of coal by gas, there will be a benefit for global warming, too) and waste. If German electricity data is used, energy recovery is better in terms of acidification, but worse in terms of resource depletion.
- No conclusion is possible regarding toxic releases. These can only be considered in a qualitative manner (especially Pb emissions to waste water of recycling vs. Pb emissions during landfilling or incineration).

From a strategic point of view, the simplified LCA is suitable for answering the questions, in spite of problems with data reliability. By the use of best guess data, scenarios etc. a better understanding of the system was achieved. An additional internal improvement assessment (not presented here) has (probably) achieved equivalent benefits as a "full" LCA.

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5 References

[1] Weitz, K.A.; Todd, J.A.; Curran, M.A.; Malkin, M.J.: Streamlining Life Cycle Assessment – Considerations and a report on the State of Practice. Int. J. LCA 1 (2), (1996) 79-85

[2] Bretz, R.; Frankhauser P.: Screening LCA for large numbers of products: Estimation tools to fill data gaps. Int. J. LCA 1 (3), (1996) 139-146

[3] SETAC Europe: Simplifying LCA: Just a Cut? – Final report of SETAC Europe (Ed.) LCA Screening and Streamlining Working Group. Brussels: May 1997

[4] Schmidt, W.-P.; Beyer, H.-M.: Life Cycle Study on a Natural Fibre Reinforced Component. Submitted to SAE proceedings of the Totoal Life Cycle Conference, 1 – 3 December 1998, Graz (Austria)

[5] Sullivan, J. L.; Costic, M. M.; Han, W.: Automotive Life Cycle Assessment: Overview, Metrics, and Examples. In: SAE, Detroit, Feb. 1998

[6] ISO 14040: Life Cycle Assessment – Principles and Framework

[7] VDI 4600: Verein Deutscher Ingenieure: Kumulierter Energieaufwand: Begriffe, Definitionen, Berechnungsmethoden

[8] Schmidt-Bleek, F.; Klüting, R.: Wieviel Umwelt braucht der Mensch? MIPS – Das Maß für ökologisches Wirtschaften. Berlin, Basel, Boston: Birkhäuser, 1993

[9] Fleischer, G.; Schmidt, W.-P.: Iterative Screening LCA in an Eco-Design Tool. Int. J. LCA 2 (1), (1997) 20-24

[10] Bauer, R.: Kumulierter Energieaufwand zur Herstellung eines Mittelklasse Pkws am Beispiel eines Ford Escort. Diploma Thesis TU München, 1993

[11] Beyer, H.-M.; Schmidt, W.-P.: Vereinfachte Ökobilanzen (Streamlined-/Screening-LCA) – Ein Konzept für interne Anwendungen. pp. 77-85. In: UTECH Berlin ´98, 17.-20.2.98

[12] Boustead, I.: Eco-profiles of the European plastics industry Report 3: Polyethylene and Polypropylene. Brüssel: APME, 1993

[13] Lübkert, B.; Virtanen, Y.; Mühlberger, M.; Ingman, J; Vallance, B.; Alber, S.: Life-Cycle Analysis: IDEA: an international database for ecoprofile analysis a tool for decision makers. International Institute for Applied Systems Analysis (ed.). Laxenburg (Austria): 1991

[14] Frischknecht, R.; Hofstetter, P; Knoepfel, I.: Ökoinventare für Energiesysteme. 2. Aufl., Zürich: ETH Zürich, 1995

[15] Umweltbundesamt: Methodik der produktbezogenen Ökobilanzen – Wirkungsbilanz und Bewertung (Federal Environmental Agency: Methodology of Product-LCA - Impact Assessment and Interpretation). UBA-Texte 23/95. Berlin: Erich Schmidt Verlag, 1995

[16] Hunt, R.G.; Boguski, T.K.; Weitz, K.; Sharma, A.: Case Studies Examing Streamlining Techniques. Int. J. LCA 3 (1), (1998) 36-42

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